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A WATER POWER AND COMPRESSED AIR TRANSMISSION PLANT FOR THE NORTH STAR MINING COMPANY, GRASS VALLEY, CAL.

By Arthur De Wint Foote, M. Am. Soc. C. E.

Presented at the Annual Convention, 1896.

WITH DISCUSSION.

Upon the prohibition of placer mining by the State of California, the immense canal systems extending over the western slopes of the Sierra Nevadas were left without a purpose, and their future existence depended upon a new use for water. Out of this necessity has grown a business of selling water for power and irrigation, retaining the original methods of delivery at the bank of the canal and miner's inch measurement. The price of water is approximately 1 cent per 1 000 galls. delivered at the canal; its cost for power depends upon the pressure that can be obtained from it. In the case of the North Star plant, it could have been conveyed directly to the mines and have done its work there on different wheels more or less adapted to the varying conditions; but there is a certain inconvenience and danger in using water in this manner under a high pressure, and, moreover, the mines are on a

hill. So it therefore seemed advisable to convey the water directly to the lowest convenient point, obtain the power there, and transmit this power to the places where it was needed.

This brought forward the subject of transmission of power, and electricity was naturally suggested first. Visits to mines in operation and careful study and investigation of electrical appliances for underground work, especially pumping, finally decided the author in favor of compressed air. The latter method, under the conditions, was believed to be most economical of power, least liable to accident, and cheapest in first cost. Moreover, almost absolute security against stoppage could be obtained by having a set of boilers on hand ready for firing up in case the water power or air plant gave out, for, by the use of these boilers and opening and shutting a few valves, all the air motors become equally good steam motors; whereas, with electrical transmission an entire set of steam motors would have to be provided to give equal security; or, as the air and steam motors are the same, the electrical motors would require just so much extra expense in cost of plant of equal security against stoppage.

To give as briefly as possible a distinct idea of this work, a concise description of the whole plant is first submitted, followed by the detailed presentation of its several parts, and, finally, the results obtained after careful tests during three months of actual working.

The water supply is obtained from the South Yuba Water Company, at a point on their canal about 4 miles from Grass Valley, Nevada County, Cal. Thence it is conveyed about 2¼ miles to the Empire Mining Company's works in a 22-in. riveted iron pipe, built more than ten years ago. The new conduit is a riveted steel pipe, 20 ins. diameter, joined to the lower end of this old one under a head of 420 ft., and continues 7 070 ft. to the power house, situated at the lowest convenient point on Wolf Creek, just below the town of Grass Valley, where a head of 775 ft., or a static pressure of 335 lbs. per square inch, is obtained. The capacity of this pipe is sufficient to develop 800 to 1 000 H. P.

At the power house there is a Pelton water wheel 18 ft. 6 ins. diameter, running on a 10-in. shaft, to which a duplex compound air compressor is connected directly. The initial cylinders are 18 ins., and the second cylinders are 10 ins. in diameter, with a 24-in. stroke. They were designed to run at 110 revolutions per minute, and require 283 H. P. from the water wheel.

A 6-in. lap-welded pipe conveys the air at 90 lbs. pressure from the power house to the company's Stockbridge shaft on Massachusetts Hill, 800 ft. distant and 125 ft. higher. Here it is now being used in a 100-H. P. cross-compound Corliss pneumatic hoisting engine, and a 75-H. P. compound pump, besides other pumps, blacksmith forge, drills, etc,

The Pipe Line.—The line of the pipe is quite crooked, both horizontally and vertically, partly because it was necessary in locating it to follow a county road. The trench was dug with plows and scrapers, except where too stony, and the joint holes were dug by hand. The joint holes cost fully as much as the trench, for the reason that many of them reached down to the harder and rockier stratum below the soft surface material. The trench was about 10 ft. wide on top, 4 to 5 ft. on the bottom, and 4 ft. deep. The joint holes were 4 to 5 ft. long and 3 ft. deeper than the trench. The total cost of all the work of burying the pipe, including covering a large portion of it with stone from the mine dumps, and cement masonry wells for the valves and for sustaining the pipes around bends, amounted to approximately $6 756.27. This was done on company account, after refusing bids, the lowest of which would have amounted to about $8 500.

An aqueduct of cement masonry across Wolf Creek at the power house is not included in this estimate, but was built on company account. As shown in Plate V, Figs. 1 and 2, it was first built up to grade; the pipe was then laid upon it and afterward covered, so that the pipe is now in the center at the tops of the arches, where the masonry section is 4 ft. square. The piers of this aqueduct are carried down to the bed-rock of the creek some 8 or 10 ft. below its water level. The lower portion of the center piers was built up of cement concrete, but the remainder of the bridge is built of the rough stone hauled from the mine dumps in the vicinity, and Portland cement and sand mixed one to three. Very little hammering was allowed, mortar being cheaper than masons. The center arches are of 33-ft. span, and the other two of 24 ft. and 28 ft., the length of aqueduct over all being 153 ft. The rock and sand each cost 75 cents per yard delivered; common labor, $2.50 per day; masons and foreman, $4 per day. The entire cost of the bridge was $1 435; as it contains about 180 cu. yds., the cost per yard was about $8. It is thought that this will prove cheaper in a few years than any other mode of carrying the pipe across the creek.

Wood or even iron would be subject to more or less change of form, sufficient to cause leakage in the pipe, but it is believed that the pipe buried in the masonry, when once tight, will never have movement enough to cause leakage. In any case, it is probable that a wooden truss bridge with stone piers would have cost nearly as much as the stone. It should be mentioned, however, that the lumber for centers is not included in the cost in this case as it could be used equally well afterward in the mine.

The steel slabs for the pipe were furnished by the Pennsylvania Steel Company. The Central Mills of Harrisburg rolled the plates, and only seven sheets of the entire lot were rejected by the inspector. The Risdon Iron and Locomotive Works of San Francisco manufactured the pipe from the 48 x 66-in. sheets and laid it complete in lengths of about 28 ft. in the trench under the following schedule, the longitudinal seams being double riveted by hydraulic riveters:

Head in Feet.	Length.	No. B. W. G.	Thickness.	Rivets.	Remarks.
420 to 500	2 320 ft.	9	0.148 in.	3/8 in.	Cold riveted
500 to 600	2 110 ft. 6 ins.	8	0.165 in.	3/8 in.	"
600 to 700	1 158 ft.	7	0.180 in.	7/16 in.	"
700 to 750	1 204 ft.	6	0.203 in.	1/2 in.	Hot riveted
750 to 775	285 ft.	5	0.220 in.	1/2 in.	"
Receiver	40 ft.	....	0.375 in.	9/16 in.	"

The specifications required a mild and very tough steel, and the cold flat bending test was insisted upon for all thicknesses. The pipe was dipped after being made into lengths into the usual hot asphaltum mixture, and then shipped by rail to Grass Valley and delivered along the trench in wagons. It was then rolled into the trench, and the lengths riveted together in place. Where there was no change in direction a slip joint was made by raising the outer end of the length with a small hand derrick, slipping the upper side into the completed portion, and catching it there through the rivet holes with bolts. Then by lowering the outer end, the weight forced the length into its place with a little care and guidance by chisels, when it was bolted ready for the riveters. Where there was a change in direction, bands were put on in two halves, lapping, but no bend piece or band was allowed with more than 4 ins. difference in width between the inside and outside. Where hot rivets were used a ¾-in. hole was punched in the top of the pipe near the end, through which the hot rivets were

PLATE V.
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FOOTE ON COMPRESSED AIR TRANSMISSION PLANT.

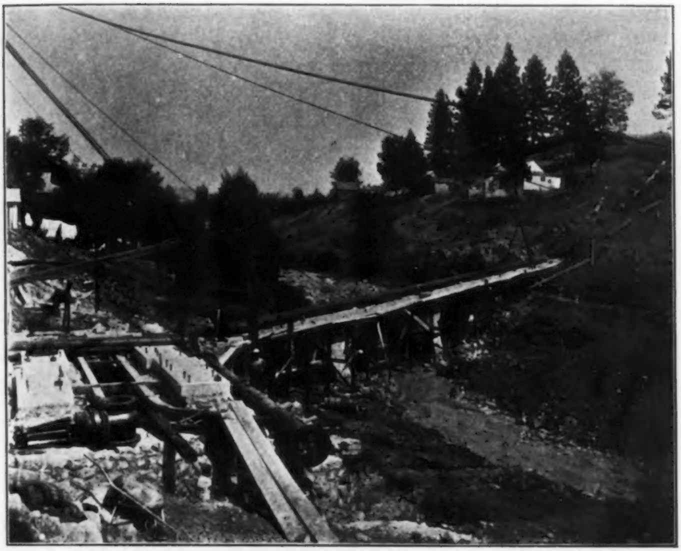

FIG. 1.

FIG. 2.

dropped to the holder-on inside. This hole was afterward stopped with a ¾-in. gas-pipe plug. P & B paint was used to cover all points not protected by the original asphaltum mixture, because it was considered preferable to the hot mixture when put on the cold metal.

In filling the pipe with water, it was quite a delicate operation to let on the full pressure at the Empire gate, as it added 180 lbs. pressure per square inch the instant the lower 7 000 ft. became full. It was done several times by keeping open a valve at the lower end of the pipe, while the Empire gate was allowing a little more to pass than the lower valve allowed to run away. In this way the pressure was not raised more than 10 or 15 lbs. above the normal. Numerous very small leaks appeared in the pipe under pressure, but neither then nor since has there been a defective rivet or plate. Fine dust from the wagon road was put into the pipe in considerable quantities, which stopped most of the smaller leaks or sweating. The attempt was made at first to mark the larger leaks, and then take off the pressure and calk them, as in the case of a steam boiler. It was soon found, however, that they would appear again as soon as the pressure was returned. Since the leaks have been calked under pressure, using proper care not to strike heavy blows, all trouble has ceased. For a time, owing to an imperfect gate at the Empire, the pressure was raised 60 to 90 lbs. almost instantly many times a day, and in consequence small leaks developed, though they were easily calked.

Close watching was necessary, however, as a stream no larger than a hair, if it happened to be turned along or against the pipe, would, with the aid of the sand it washed in, cut the pipe badly in a few hours. In one instance two threads of water, so small that they failed to wet the earth upward to the surface, shot out at right angles to each other, one from the longitudinal seam, and one from the circular seam near their intersection. These streams, striking each other, formed a miniature whirlpool, which bored a hole through the pipe about the size and shape of the point of a lead pencil, letting out a larger stream which soon led to its discovery. Where sharp bends were necessary, the pipe, as laid in the trench, was packed on the outer side of the bend by grouting and cement masonry between the pipe and the side of the trench for the full thickness of the pipe.

About 1 000 ft. from the lower end a 12-in. branch with a gate is put in for possible future use, and adjoining it on the lower side a

20-in. gate. These are buried in cement masonry, to prevent any movement from thrust when the latter gate is closed, and over all is built a cement masonry gate house 12 ft. square, which answers also for a tool house. At the lower end of the pipe in the power house there is another 20-in. gate, below which is a 12-in. branch leading to the Pelton wheel, and adjoining this is the receiver, 2 ft. in diameter, on which are the air chambers, charging tube and relief valve. The lower end is stopped with a flanged end, bolted on, which can easily be removed for extending the receiver for additional power.

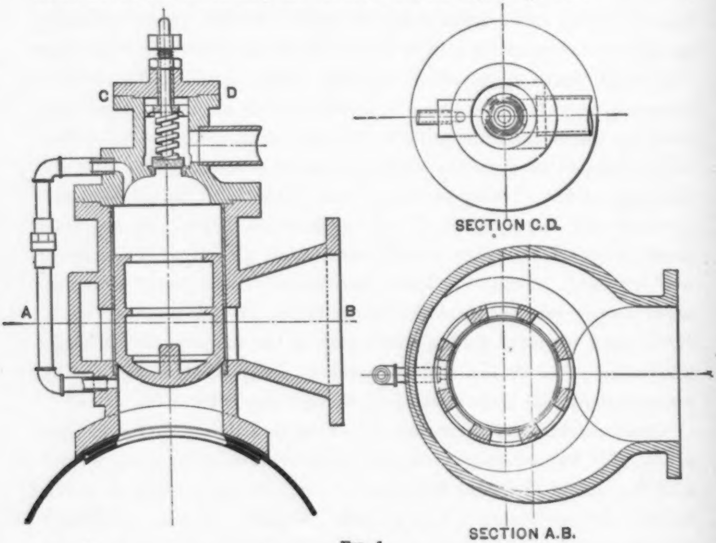

FIG. 1.

The air chamber is a 10-in. lap-welded tube 18 ft. long standing on the receiver, with an 8-in. gate between. The charging tube is similar, but 8 ins. in diameter. Both have 2-in. water discharge pipes and gates, and by proper manipulation of the gates and the operation of inlet check valves on top of the tubes, the air chamber may be filled. Ordinarily the charging-tube is filled up to 90 lbs. pressure from the air compressor delivery pipe, and then raised by the water pressure. It is found necessary to put in about one-tenth of the volume of the air-chamber every day. Where the air goes is, thus far, a mystery, as no leak has been discovered.

The relief valve was designed by Mr. H. Schussler, Chief Engineer of the Spring Valley Water-Works of San Francisco, and is the first of its kind ever made. It is shown in Fig. 1. It seems perfect for the purpose, except that the small pop-valve leaks continually. It is hoped that this fault may be remedied by using a different form of valve. It can be set to open at about 35 lbs. above normal, and will close without jar or hammer. In action, the pressure rises until it lifts a pop-valve in the ordinary way; when this is raised the pressure is relieved on top of an 8-in. piston, slightly larger at the top end, which rises and opens the ports of an 8-in. outlet. The pressure going down, the pop-valve closes and equalizes the pressure on both ends of the piston, gradually closing it. If the proper pop-valve can be procured, this relief valve will prove a sure safeguard for the pipe. On one occasion already, when from some unknown source a piece of drift wood entered the nozzle and stopped the flow of water instantly, this relief valve saved the pipe from serious shock, if not actual bursting.

Water Wheel.—The demand for direct action under a head of 775 ft. made a large wheel necessary in order to obtain the proper peripheral speed of half the spouting velocity. The manufacturers objected seriously to undertaking anything over 15 ft. in diameter; whereas the proper speed of 60 to 70 revolutions for the compressors required a wheel of nearly 30 ft. diameter. A compromise was finally made with a wheel of 18 ft. 6 ins. diameter, and a compressor revolution of 110 per minute, and the Pelton Water-Wheel Company, of San Francisco, built the wheel from a design by Mr. E. S. Cobb. Had the design been prepared sooner, the wheel could have been made 30 ft. in diameter equally well. The Pelton Company guaranteed an efficiency of 85% at full load, and an average of 75% from half to full load of the theoretical power of the water, and, at the same time, to so govern the wheel that it should not exceed 120 revolutions nor raise the air pressure above 105 lbs. per square inch in case of accident to machinery or sudden shutting off of air. As shown in Plate VI, the rim is built up of angles and plates riveted together to break joints. It weighs about 6 800 lbs., and is held concentric with the shaft by 12 pairs of radial spokes of 1¼-in. rod iron held by nuts to the cast-iron hub. The driving force, being applied to the rim, is transferred to the hub by four pairs of 2-in. iron rods, so arranged as to form a truss, shown

also in Plate VI. Without going into the calculations for strains, which are given as furnished by Mr. Cobb in Appendix No. 1, it may be stated that the factor of safety is very large for all the strains likely to come on the wheel.

The wheel is set on a 10-in. shaft, having a disk crank on either end connected directly to the compressors. The wheel was easily lined up by the nuts on each end of the radial spokes to run almost perfectly true. After a few weeks' use it was found to have worked slightly and was straightened again. It balanced so well that upon shutting off the water it was 14½ minutes coming to rest from 110 revolutions per minute, when disconnected from the compressors. The regulator is a floating valve actuated against excessive velocity by the ordinary ball governor and against excessive air pressure by a spring set to move when the air pressure in the delivery pipe exceeds 90 lbs. This floating valve admits water on either end of a hydraulic piston which operates a lever moving a hood up and down over the head of the nozzle, thus shutting off or letting the water on to the wheel as the air pressure becomes too great or as the speed gets above or below 110 revolutions. This regulator has now operated the wheel for several weeks and seems almost human in handling its speed. The load can be thrown off entirely and the governor will hold the wheel to 120 revolutions or less, and if all the air motors happen to be shut down the air pressure will increase rapidly and the wheel slow down, until at 100 lbs. it will stop.

The compressors are so arranged, as will be shown further on, as to admit of being run at one-quarter, a half, three-quarters or full power. It was quite an object, therefore, to have a water wheel which would give as nearly as possible the full efficiency under these different heads. For this purpose there are four nozzles, one for each of the heads required, and, as the machine must be stopped to change its capacity from one load to another, it is no great inconvenience to change nozzles at the same time, requiring perhaps three minutes. It was of considerable interest to know just what the efficiency of so large a wheel might be, and it was also necessary to measure the water quite accurately for business purposes; therefore a measuring flume 18 ft. long and 6 ft. 9 ins. wide was constructed to take the tail water on leaving the building. The overflow is a sharp-edged iron about 3 ins. high and 15 ins. above the bottom of the flume. No contractions are made.

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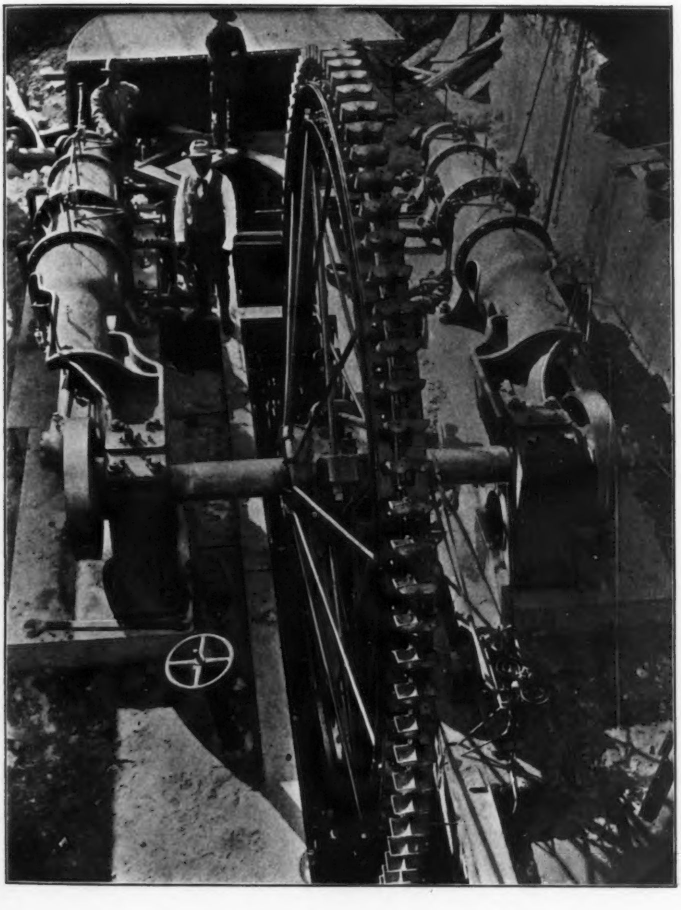

An 8-in. pipe about 6 ft. above the overflow connects with the gauge box, within which is the measuring scale for the hooked gauge. Great care was used in making the whole apparatus as perfect as possible, and it is believed that the average result of many measurements is within 1% of being correct. The power developed by the wheel was found by taking a large number of indicator cards from the compressors. These were averaged and the friction added, which was found by first running one compressor and afterward running it with the other compressor with the valves out; the difference in the quantity of water used was measured and the horse-power of this water was called two-thirds of the friction of the machine when loaded, which was equivalent to allowing 50% for load. The friction of the water wheel and its bearings is included in its efficiency. Repeated tests which checked very closely give the wheel an efficiency of a trifle over 90% for one-quarter, one-half, three-quarters and full loads. Between these points it is somewhat less, as the hood coming down over the nozzle tends to deflect the water as well as hold it back, and decreases the efficiency. It seems probable that the long radius of the wheel accounts for the high efficiency.

The illustration of the wheel shown in Plate VI was taken before the wheel was tried. The buckets were soon found to be too near together, and one-half of them were taken off. Actual working has shown that this wheel has great efficiency at low speed. It began working under half load, using the half-load nozzle. Gradually in pumping out the mine, as the pumps were lowered and more power was needed, the limit of the machine while running one compressor at 110 to 115 revolutions was reached, and the opposite compressor was connected on, the intention being to run three-quarters load with the three-quarter nozzle. As an experiment, both compressors were connected as if for full load, and the half-load nozzle was retained. The result showed considerable more power delivered with both compressors running at 54 to 65 revolutions than was obtained before with one compressor at 115 to 120, so much, indeed, that the works were kept running over two weeks longer with the half-load nozzle, though the pumps were lowered on an average 18 ins. per day. Of course a large portion of the gain in power can be attributed to the saving in friction and improved working of the compressors under the slow motion, but yet it must be true that the wheel loses very little in its effici-

ency, compared with the accepted ideas of loss in wheel efficiency, working under a peripheral speed of one-quarter of the spouting velocity.

Compressors.—Mr. E. A. Rix, of San Francisco, who has made a careful study of air compression, designed the compressors shown in Plate VI, and they were built by the Fulton Engineering and Ship-Building Company of San Francisco. They are made very heavy to stand the high piston speed required by the conditions of the water power. Had it been known at the time of designing this plant that a wheel could have been made like the one described, a diameter of 30 ft. instead of 18 ft. would have been chosen and the piston speed of the compressors reduced accordingly, for there is no question but that 60 to 70 revolutions will do better work than 110. The compressor cylinders are 18 and 10 ins. in diameter and 24 ins. stroke, with a water jacket so arranged that two streams of water pass around the cylinders in opposite directions. The inlet valves are of the Brenner pattern and open directly into the power room. Mechanical valves and air inlets from the wheel pit were considered, but taking into consideration the class of mechanics likely to handle the machine, and its remoteness from the shops, it was decided to adopt the simplest valves and place them so as to be reached easily. The compressor cylinders were made sufficiently large to allow for the rarefaction of the air caused by the automatic valve, and all the air that enters the building is forced to come up through the wheel pit. The other valves are made after the pattern of ammonia compressors.

The most novel feature of these machines is the intercooler. This is made up of 49 soft copper pipes, 1 in. in diameter, 18 ft. long, each with a stuffing-box at each end connected with manifold castings. The air delivered from the first cylinder into one manifold passes through these pipes to the other manifold, from which it is taken to the second cylinder. The whole is placed in the wheel pit directly under and in front of the wheel, so that the water dashes all over and through it. The air leaving the first cylinder at a temperature of 200° Fahr., passes through the intercooler and enters the second cylinder at 60°, slightly cooler than when entering the first cylinder. The temperature is again raised to 204° on leaving the second cylinder and passing into the transmission pipe, showing a total rise in temperature of 282° Fahr.

The transmission pipe, conducting the air at 90 to 100 lbs. pressure about 800 ft. from the compressors to works at the mine, is ordinary

well tubing 5¾ ins. in diameter inside, screwed together in the trench and bent to fit the uneven ground by building fires around it and heating it until its own weight shaped it to the surface. After being laid and covered, it was tested by filling it with water under 120 lbs. pressure, which was allowed to stand over night. No leakage was discovered and none has appeared since. As yet only half of the full load of air has been passed through this pipe, so no data of value regarding loss in transmission through pipes have been obtained. With the present load the difference in pressure between the power house and the mine is not sufficient to be detected on the ordinary pressure gauge. At the mine there is the ordinary air receiver, and also three 50 H. P. boilers set ready for steam, which are used for receivers.

The air is taken from these into the reheaters designed by Mr. Rix and built by the Fulton Company. As these are the first of their kind, it may be said they have proved remarkably well designed for their work. Experience has shown, however, that slight improvements can be made which would save fuel. At present it requires a little over half a cord of good pine wood each 24 hours to heat about 700 cu. ft. of free air per minute to a temperature of 350 to 400° Fahr.

The heated air passes through pipes covered with magnesia and hair-felt to the first cylinder of the hoisting engine, from which it is exhausted back into the upper heater, where its temperature is again brought to 350°, whence it passes to the second cylinder at 30 lbs. pressure. From this it is exhausted through a flue to the change house, where it is used for heating and drying clothes. From the first heater also the air for the pump is conveyed some 300 ft. down the shaft in a similarly covered pipe. The pump was designed and built by Mr. George E. Dow, of San Francisco, and is a tandem compound vertical sinking pump of a capacity of 500 galls. 300 ft. high per minute. It receives the air at about 275° and exhausts it into the shaft at about 60°, thus giving plenty of pure cool air to the men, without the usual fans or ventilators. At the present writing, this pump is throwing 600 galls. per minute 240 ft. high.

In addition there is a direct-acting donkey pump throwing 350 galls. 110 ft. high situated in another shaft 750 ft. distant, to which air is carried cold in a 2-in. pipe over the surface. An old hot-water heater is used as a reheater for the air, and consumes 12 sticks of pine cord wood per 24 hours.

The hoisting engine is a compound direct-acting Corliss of 100 H. P. with cylinders jacketed for hot air, and is calculated to work 3 000 ft. down an incline of about 35 degrees. This was also designed by Mr. Rix and built by the Fulton Company. While it is especially adapted to the use of heated air, it takes steam as well as any engine and in fact was first tested with steam.

Efficiencies.—Efficiencies often seem to depend largely on the personal equation of the reporter. Mr. Rix's summary of tests is given in Appendix No. 2. He spent a number of weeks making them, and while agreeing with him in the main, the following are submitted as the author's conclusions. In any case, the plain tale is this. There is 304 theoretical H. P. in the water used at the power house, the work actually accomplished at the mine amounts to 203 H. P., and the cost of reheating is $3 per day.

Efficiency of compression and transmission from water wheel to motors, and not including cost of reheating................ $\frac{225.32}{283} = 79.5$ per cent.

Efficiency of compression and transmission from theoretical power of the water to the motors, and not including cost of reheating: $\frac{225.32}{304} = 74$ per cent.

Efficiency from the water wheel to and through the motors, not including reheating...... $\frac{202.7}{283} = 71.6$ per cent.

Efficiency from the theoretical power of the water, to and through the motors, and not including the cost of reheating.......... $\frac{202.7}{304} = 66$ per cent.

Efficiency of compression and transmission from water wheel to motors, including the cost of reheating expressed in water power: $\frac{225.32}{307.66} = 73$ per cent.

Efficiency of compression and transmission from the theoretical power of the water to the motors, including the cost of reheating expressed in water power............. $\frac{225.32}{329} = 68.4$ per cent.

Efficiency of compression and transmission from the water wheel to and through motors, including cost of reheating expressed in water power.......................... $\frac{202.7}{307.66} = 65.5$ per cent.

Efficiency of compression and transmission from the theoretical power of water to and through the motors, including cost of reheating expressed in water power....... $\frac{202.7}{329} = 61.6$ per cent.

Horse power of air at works after reheating: 225.32.
Horse power delivered to compressors by water wheel: 283.
Theoretical horse power of water used on the wheel: 304.
Horse power of work actually done by the motors: 202.7.
The horse power delivered by the water wheel to the compressor, to which is added the horse power (24.66) which the cost of the wood used in reheating would buy in water: $307.66 = 283 + 24.66$.
The theoretical horse power of the water used on wheel added to the horse power (24.66) which the cost of the wood used in reheating would buy in water: $329 = 304 + 24.66$.

After nearly three months' working of the plant, the author believes the results obtained demonstrate the wisdom of having chosen air instead of electricity.

It may be urged that the conditions are particularly favorable to compressed air, as the transmission is short and the power is not needed for tramways or lighting. For lighting it is admitted without question, and possibly for tramways, that electricity is preferable, but for transmission, were it 20 miles instead of 1 000 feet, it is thought by the author that, taking the whole plant, compressor, transmission pipe and motor, as against generator, transmission wires, transformers, and electric motors, the air will prove cheaper in first cost, higher in efficiency, less liable to accident, and less expensive to operate and maintain.

The sense of being solidly supported in his plans and expenditures and encouraged to make his work thorough by the money power behind him is so rare in the experience of the American engineer as to be worthy of grateful mention; but still more rarely does he find, united to this material backing, the moral support which comes of the comprehension and sympathy of a wise engineer. This was the great good fortune of the author in carrying out the decision in favor of compressed air transmission and other somewhat novel features of the plant, under the sanction of Mr. James D. Hague, the President of the North Star Mining Company.

APPENDIX No. 1.

THE PROBLEM OF THE WHEEL.

By E. S. Cobb, Esq.

The problem is to design a wheel, the total weight of which is to be 10 000 lbs., as nearly as possible, the diameter 18 ft. 4 ins., the rim of suitable section to receive the buckets of a Pelton water wheel, and the whole strong enough to be in continuous use at 110 revolutions per minute while transmitting 226 H. P. from rim to shaft.

The cross-section of rim adopted is shown in Fig. 2. It is made up as follows:

Two 6 × 4 × ⅝-in. angles, weighing 20 lbs. per foot, 40 lbs. per foot of rim.

Four 4 × 4 × ⅝-in. angles, weighing 15½ lbs. per foot, 62 lbs. per foot of rim.

Center plate ¾ in. thick, 28 lbs. per foot of rim.

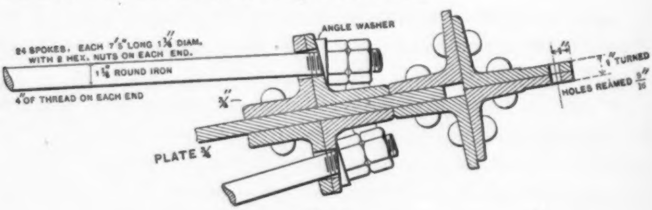

Fig. 2.

The mean diameter of the rim is 16 ft., and the average weight per foot is 135.2 lbs., including rivet heads. The total weight of the rim is 6 800 lbs.

The rim is held concentric with the shaft by twelve pairs of radial spokes. Strictly speaking, however, these spokes are at a slight angle with the plane of revolution, and this angle is taken into account in the calculations.

For the purpose of determining the maximum strain in working that may be expected by one pair of spokes, the rim is assumed to be cut into twelve pieces, each piece weighing 575 lbs., and being held in position against centrifugal force by one pair of spokes. Then the strain on each pair of radial spokes due to the velocity is found as follows:

Centrifugal force $= \dfrac{\text{weight} \times \text{radius} \times \text{rev.}^2}{2\,936}$. Substituting the proper quantities $\dfrac{575 \times 8 \times 12\,100}{2\,936} = 18\,958$ lbs., or 9 479 lbs. per spoke.

By reason of the position of the spoke at an angle with the plane of revolution, this strain becomes 10 000 lbs. per spoke. As 1¼-in. round iron is used, there is at the bottom of threads a safe area of 0.7854 sq. in., or a strain of 12 700 lbs. per square inch of section, on the assumption that these rods hold the whole of the centrifugal force acting in the rim, without any aid from the strength of the rim itself.

The strain at the least cross-section of the rim when it sustains its own centrifugal force without any aid from the radial spokes is as follows:

$$\frac{135.2 \times 8 \times 12\,100}{2\,936} = 4\,458 \text{ lbs.}$$

nearly, per foot of diameter. At 16 ft. average diameter, the total bursting strain of 71 328 lbs. is held by two sections, or 35 664 lbs.

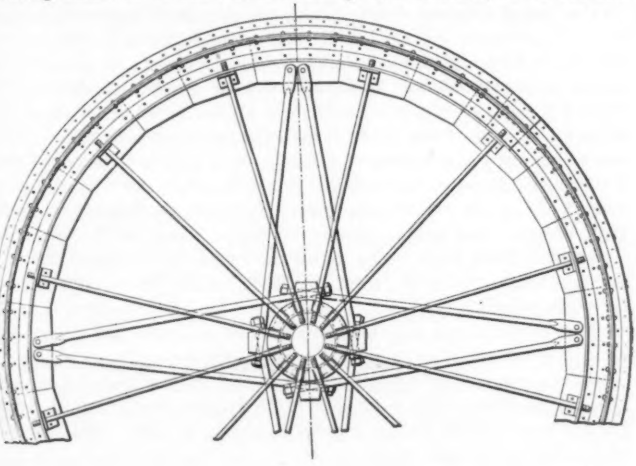

FIG. 3.

per least cross-section. The least cross-section of the rim is the section of the six angle irons, or 30.6 sq. ins. Deducting 25% for unknown imperfections and rivet holes leaves about 23 sq. ins. area, giving a strain of 1 550 lbs. per square inch of rim, when it alone is sustaining all the strain due to centrifugal force.

Power being applied to rim to develop 226 H. P. at 110 revolutions per minute, there results as the tangential strain at the ends of the truss rods 1 500 lbs., or 375 lbs. tangential strain at the end of each truss rod. This tangential strain produces in the rod, on account of its position, a tensile strain of 2 207 lbs., or 1 100 lbs. per square inch of net cross-section when seven threads are allowed for.

The general form of the wheel is shown in Fig. 3.

APPENDIX No. 2.

SUMMARY OF TESTS OF THE NORTH STAR POWER AND TRANSMISSION PLANT.

By E. A. Rix, Esq.

Actual capacity of compressor, 1 412 cu. ft. of free air compressed to 90 lbs. gauge.

Volumetric efficiency, 96.6%, determined as follows:

Barometer pressure, 13.42. At 90 lbs. gauge, compression ratio is $103.42 \div 13.42 = 7.7$. Receiver, air pipe, and all storage, reduced to 90 lbs. gauge, contained 291 cu. ft., which equals 2 240 cu. ft. of free air. Compressor averaged 102½ revolutions to fill this at 90 lbs. from 25 lbs., which was intercooler pressure. Receiver, etc., at 25 lbs. gauge contained 830 cu. ft. free air. $2\,240 - 830 = 1\,410$ cu. ft. delivered by 102½ revolutions; deducting 2% for increase of temperature in receiver makes 1 382 cu. ft. at 60°, the outside temperature. Theoretical capacity of compressor, 1 429 cu. ft. at 102½ revolutions, $1\,382 \div 1\,429 = 96.6\%$ volumetric efficiency. Reduced to 110 revolutions, this gives 1 412 cu. ft. working capacity. To compress this, 304 theoretical H. P. of water was used on 18-ft. 6-in. Pelton wheel, at 110 revolutions.

The indicated horse power in all the cylinders averaged 250 H. P., and friction load 22 H. P.; total, 272 H. P. $272 \div 304 = 90\%$ efficiency for water wheel.

This friction load was determined when machine had no pressure on it, but was running at normal speed. Experiments on steam compressors show that the friction load is 50% more under full work. This would, then, be $22 + 11 = 33$ H. P. friction load, making total of $272 + 11$, or 283 H. P. delivered by wheel, or $283 \div 304 = 93\%$ of theoretical power in water.

The head of water on the wheel is 730 ft.

The work of compression and delivery is $250 \div 304 \doteq 82.2\%$ of the theoretical horse power, or $250 \div 283 = 88.3\%$ of horse power delivered by wheel.

The 1 412 cu. ft. of air is reheated to 350° Fahr., and, considering that it is used in a compound Corliss engine with intermediate reheating, the theoretical potential in the air before use is 225.32 H. P., determined as follows:

The cylinders being jacketed for hot air the Y which is used in calculations is the same as that used for compound, jacketed compression, viz., 1.3; then

$$Y = 1.3; \quad Y - 1 = 0.3; \quad \frac{Y-1}{Y} = 0.23; \quad \frac{Y}{Y-1} = 4.33.$$

Barometric pressure = 13.42. Outside temperature, 60° Fahr.

The work being equally distributed between the two cylinders, the intermediate pressure will be the mean proportional between the initial and final pressures. Initial pressure, 90 + 13.42 = 103.42. Final pressure, 13.42 + 1 = 14.42 (1 being the exhaust pressure above atmosphere). Then $\sqrt{103.42 \times 14.42} = 38.62$, absolute intermediate pressure. The formula for the work in the cylinders will then be:

$$\frac{\frac{Y}{Y-1} P\, V \frac{T_3}{T}\left(1-\frac{p_2}{p_1}\right)\left(\frac{Y-1}{Y}\right)}{33\,000}$$

in which the elements are

$$\frac{Y}{Y-1} = 4.33$$

P = barometric pressure per square foot = 13.42 × 144.
V = cubic feet free air.
T_3 = temperature of reheating, absolute = 461 + 350 = 811.
T = absolute outside temperature = 461 + 60 = 521.
p_2 = intermediate pressure = 38.62.
p_1 = initial pressure = 103.42, and

$$\frac{Y-1}{Y} = 0.23.$$

Then substituting, the equation becomes:

$$\frac{4.33 \times 13.42 \times 144 \times 1\,412 \times \frac{811}{521}\left(1 - \frac{38.62}{103.42}\right)0.23.}{33\,000.}$$

Or 554.96 × 0.203 = 112.66 H. P. in one cylinder, or 225.32 H. P. in two cylinders.

Inasmuch as \$3 worth of wood, or its equivalent, 15 ins. of water at 20 cents an inch, has to be added for reheating, the following allowance must be made for this: 15 ins. of water under 730 ft. head equals 30 H. P. The work of compression and delivery being 82% of the theoretical horse power, 30 × 82.2, or 24.66, represents the actual value of power delivered to the air to account for reheating, then, 250 + 24.66 = 274.66 is the total power spent on the air It has a theoretical potential of 225.32 and consequently 225.32 ÷ 274.66 = 82 per cent. Counting from the theoretical power in the water, the efficiency would be 225 ÷ 304 = 74 per cent.

This 82% represents the efficiency of the compressed air system under unfavorable circumstances. It was deemed advisable to have the water wheel on the compressor shaft, and 18½ ft. was the limit of diameter which could be contracted for. This made a revolution speed of 110, and a piston speed of 440, which reached 660 ft. at the half stroke just when discharge was beginning from the cylinders. These piston speeds are too high for economical work. Running the water wheel throttled at 80 revolutions, or a piston speed of 320 ft., the indicator cards showed a horse power of 247, including the friction load. This

would show an efficiency of $225.32 \div 247 = 90\%$, or from the theoretical water power $225 \div 275 = 80\%$, and were the same plant to be built again this could easily be attained, because it has been ascertained from the experience with the present water wheel that its diameter can be increased so as to run at 80 revolutions.

What power value will be in this 90% efficiency will depend largely on the motors used. The theoretical potential was calculated on the assumption that compound Corliss, jacketed, double-reheated engines should be used. Allowing that these engines have a mechanical efficiency of 90%, which is not a high efficiency, the horse power realized will be 90×90, or 81% of the indicated horse power of the compressors, or $90 \times 80 = 72\%$ of the theoretical value of the water power. With other classes of motors, the value of their work can be proportioned to the above percentages directly as their economic value is to that of the compound Corliss motor from which the air potential was assumed.

When the pump was first started it made 71 strokes, theoretically 710 galls., or 5 893 lbs. The pump has a volumetric efficiency of 95%, which would make this quantity 839 752 foot-pounds. This was done with the compressor running at 80, and the air pressure at 90. At the present time, the pump is making 60 strokes or 4 980 lbs., pumping 230 ft., making 1 145 400 foot-pounds, or, at 95% volumetric efficiency, 1 088 130 foot-pounds. This is being done with 93 single revolutions, at 90 lbs.

The compressor is making 90 single revolutions at an average of 92½ lbs. pressure, which is equivalent to 93 single revolutions at 90 lbs., in order to reduce both the performances to the same pressure.

The difference between the foot-pounds of work in both of these cases, viz., 1 088 130 — 839 752 is 248 378 foot-pounds. The difference in revolutions is 13; consequently 13 revolutions did 248 378 foot-pounds of work, or 19 100 foot-pounds for one single revolution.

It is evident that this work is what the pump is capable of doing, independent of its friction of pipes, etc., because the friction of the pump and the friction of the pipes within the small working limits of this pump are practically the same, as will be seen from the following: For 93 single revolutions, were there no friction of pipes or inertia of pump to overcome, it is evident the pump should perform 93 times 19 100 foot-pounds of work, or 1 776 300 foot-pounds. It really did 1 088 130 foot-pounds, the difference being 688 170 foot-pounds, which is the friction of the pipes and inertia losses.

In the other case 80 revolutions should have done 80 times 19 100, or 1 528 000. It actually did 839 752, the difference being 688 248, again almost identical with the first proposition. So the mean between these two, or 688 209 foot-pounds, is the actual pump loss, and this loss it would seem is almost the same at any head within the working limits of the pump.

The loss now being determined, it is possible to determine what actual work is being done, and if the pump efficiency is determined, a check can be made on the potential of the compressor.

If at 93 revolutions the pump does 1 088 130 foot-pounds of work, and the friction is 688 248 foot-pounds, and 19 100 foot-pounds are added for each single revolution of the compressor up to its limit of speed, viz., 220 single revolutions, this last amount being 2 425 700 foot-pounds, there would result a total of 4 202 078 foot-pounds of work which the pump would do when the compressor is running its 220 single revolutions, or its limit. If there is deducted from this amount the friction and inertia loss of 688 248 foot-pounds, the result is 3 513 830 foot-pounds, which is the useful effort of the pump, and the ratio between what the pump actually does and the foot-pounds of work it consumes, would be its efficiency, which, upon dividing these sums by each other, shows the mechanical efficiency of the pump to be 83 per cent.

If the potential of the compressor is 225.32 H. P. and the efficiency of the typical motor is 90%, then the brake horse power possible for the typical motor would be 225.32 times 0.9, or 202.7 H. P. for 220 single revolutions of the compressor. For one revolution it would be 0.992, which is 30 426 foot-pounds.

The pump actually does 19 100 foot-pounds for one revolution. The ratio therefore between 19 100 which the pump actually does, and 30 426 which the typical motor would be capable of, would be the pump efficiency as compared to that of the motor. This would be 62 per cent. This includes temperature, the friction in pipes and inertia losses between the reheater and the pump exhaust.

Inasmuch as the pump did 4 202 076 foot-pounds of work with an efficiency of 62%, as compared to the typical motor, the typical motor would yield 4 202 076 ÷ 0.62 = 6 600 000 foot-pounds, or 200 H. P., which compares very favorably with the original calculations for the brake horse power at the potential as being 202.7.

Recapitulating these figures:

The total work done by the pump	=	4 202 076	foot-pounds.
The total brake horse power of the ideal motor	=	6 600 000	"
The total potential of the air after reheating	=	7 434 900	"
The total work spent on the air, including the energy of reheating at 440 ft. piston speed..............................	=	9 042 000	"
The total work spent on the air, including the energy of reheating at 320 ft. piston speed	=	8 215 000	"
Theoretical power of the water at 440 ft. piston speed	=	10 032 000	"

Theoretical power of the water at 320 ft. piston speed........................ = 9 205 000 foot-pounds.
Total power of the water, including the energy of reheating at 440 ft. piston speed.............................. = 10 692 000 "
Total power of the water, including the energy of reheating at 320 ft. piston speed.............................. = 9 865 000 "

Under the lower piston speed, which should be the proper speed to run the compressor, the ratio of original power and reheating, 9 860 000 foot-pounds, and the total pump result, 4 202 000 foot-pounds, would be 44%, which would be the efficiency from first to last as far as the pump system was concerned, and the ratio between any other of the elements in the preceding recapitulation will be their relative percentages.

DISCUSSION.

S. S. Wheeler, M. Am. Soc. C. E.—While the theoretical power of the water is stated very clearly, there are few figures to indicate exactly the amount of useful work done. The hoisting engine is stated to have a capacity of 100 H. P., but no information is given showing how much work it actually does, and the same remark applies to the other machinery. More definite information on this part of the subject is needed. Mr. Wheeler.

William Doble, Esq.—It is impossible to compare financially the plant described in the paper with one using electricity for the same purpose, since the author has not given any figures of cost of his apparatus. There would have been a saving in the first cost, however, for a 6-ft. water wheel would have been ample to run the generator, and would have cost about one-fifth as much as that installed; the electric generators would have cost less per horse-power than the compressors, and the freight charges on them and the smaller wheel would have been less, and the cost of wiring would have been less than that of the pipes used to convey the compressed air to and into the mines. The cost of installing the electric plant would also have been less, particularly on account of its smaller foundations. The use of covered hot-air pipes in the shafts presents drawbacks which are avoided where electric wires are employed. The pumping plant described in the paper may be compared with one employing electricity which was installed in another mine to handle about 240 galls. of water a minute under a vertical lift of 468 ft. In the latter case, the theoretical power required was 30.1 H. P.; the amount actually delivered was 40 H. P., conducted by two wires instead of large covered hot-air pipes. Another advantage of electrical apparatus over that using compressed air is that it is more easily operated and more economical in operation. The compressor has to be stopped whenever the load varies enough to make it necessary to change the nozzle of the wheels, whereas with an electric generator the varying loads are taken care of automatically in the generator. The guaranteed efficiency with generators at one-quarter load is 85%, and from that condition rises to 95% at full load; higher efficiencies than that can be obtained with air compressors. Mr. Doble.

CORRESPONDENCE.

Mr. Young. C. G. Young, Assoc. Am. Soc. C. E.—On examining carefully the efficiencies given in the paper, it will be found that only about three-tenths of the power developed by the motors has been transmitted, while seven-tenths has been developed at the reheater. Consequently the plant does not furnish an instance of real power transmission; in fact, hot-air engines without transmission of power from other prime movers are comparable to the case in question and would be nearly as efficient.

It has not yet been demonstrated that compressed air can be transmitted economically for power purposes to any great distance. In most cases it is inconvenient, if not impracticable, to use a reheater at the motor, and unless the reheater is very near the motor, its advantages will be lost. The necessity of such an apparatus will prevent the adoption of compressed air for extensive distribution of power, while the expense of pipe lines and the attendant losses will prevent its adoption for transmission of power to any great distance.

The great loss in air compression can be appreciated when it is considered that all the energy is represented in raising the temperature, and that when the latter falls the difference in temperature represents the energy lost which cannot be regained. Pipes for transmission to any great distance would be very expensive, the allowable pressure would be comparatively low, and the losses in energy would be considerable. The air motor is very inefficient, even when the air is reheated; the reheater is an efficient apparatus, and on this depends the success or failure of a compressed air plant.

In the following comparative table of compressed air and electric transmission of power to a distance of 20 miles, using water power as the source of power, the very high efficiencies given in the paper have been used.

Efficiencies with Compressed Air.		Efficiencies with Electricity.	
Wheel	93%	Wheel	93%
Compressor	88%	Generator	95%
Transmission and reheating	83%	Line and transformer	88%
Total, without motor	68%	Total, without motor	78%

This shows a considerable advantage for electrical transmission. In cases where the reheater cannot be used, the efficiency of compressed air would fall to about 30 per cent. The data given for the electrical apparatus are obtainable in regular practice. The efficiency of the water-wheel appears high, and probably 85% would agree better with the usual conditions; this would lower the total efficiency of air transmission to 62%, and of electrical transmission to 71 per cent. The

efficiencies given in the paper appear very high, and it is doubtful if they can be maintained in regular practice. Mr. Frank Richards states in his book entitled "Compressed Air," that the net efficiency of modern air compressors in actual practice is never above 80%, and is often below 60 per cent. Assuming 70% as a fair average, the comparison given in the preceding table would be changed to show total efficiencies of 49% and 71% for compressed air and electricity respectively. Mr. Richards claims that it is practically impossible to double the power at the reheater on account of the excessively high temperatures required, and that in the best practice not over 30% is added to the power at the reheater. These statements differ considerably from the author's figures. Mr. Young.

The cost of electric generators and motors would not be more than the cost of compressors, reheaters and air engines, while the copper transmission line would be cheaper than a pipe line and could be erected in places where it would be impossible to lay a pipe line. The cost of a copper transmission line on wooden poles, capable of delivering 10 000 H. P. to the motors 20 miles distant, with a loss of 10%, using 30 000 volts, would be about $35 000. This is about 33 cents per foot. It is evident that a pipe line capable of transmitting 10 000 H. P. a distance of 20 miles, with a loss of 10%, cannot be built at this price. The plant described in the paper is apparently a good example of a compressed air system for transmission a short distance, but an electric plant installed under the same circumstances ought to show better results at a smaller cost. The voltage could be kept low and be suitable for lighting. Electrically operated pumps and drills are fully as efficient as those driven by compressed air, and more portable. No auxiliary set of boilers would be needed in the case of an electric plant, for there would be two electric generators and two or more circuits, so in case of trouble only a portion of the plant would be affected.

The writer desires to ask the author to state the horse-power in the air at the works before reheating, and to compare this with the horse-power at the water-wheel; also to state the pressure, loss in transmission, and size of pipe for delivering 10 000 H. P. to motors 20 miles distant, and the amount of power he would generate at the reheaters in this case.

A. D. Foote, M. Am. Soc. C. E.—Mr. Young states that "only about three-tenths of the power developed by the motors has been transmitted, while seven-tenths has been developed at the reheater." A more careful reading of the paper would have shown him that about seven-tenths of the power is transmitted, and about three-tenths developed at the reheater. Consequently, his remark that this plant does not furnish an instance of real power transmission and his comparison with hot-air engines do not apply. Mr. Foote.

Mr. Foote. Again, quoting Mr. Young: "The great loss in air compression can be appreciated when it is considered that all the energy is represented in raising the temperature." Were this true, there would be no power left in the air after being compressed and cooled.

Mr. Young says: "The air motor is very inefficient, even when the air is reheated." The reply to this is that the compound Corliss engine is more efficient when working with compressed air than it is with steam, as has been proved by practice, and becomes still more efficient by reheating the air between the cylinders, as is being done in the plant described in the paper.

In the comparative table of efficiencies, as between compressed air and electricity, given by Mr. Young, his efficiencies for electrical transmission may possibly be attained at full load, under ideal conditions; but a transmission plant very seldom is worked at full load, and in air transmission the efficiencies as obtained in working are not perceptibly different, whatever the load, as has been demonstrated by nine months' working of the North Star plant.

Mr. Young presents an average of Mr. Richard's best and worst air compression as a foundation for comparing electric and air transmission. It seems more proper to assume that in putting up a plant the best compressors would be used; and it is proved by work now being done that Mr. Richard's figures are not the last word on air compression.

Mr. Young's statement that the "cost of electric generators and motors would not be more than the cost of compressors, reheaters and air engines," does not agree with the author's experience. The bids from the electrical companies for the North Star plant machinery were considerably more than the actual cost of the air machinery in place. The air transmission pipe cost 55 cents per foot. If Mr. Young could see the pipe-laying that has been done by western engineers in the Sierra Nevadas, he would realize that there is very little of the earth's surface over which a pipe-line cannot be laid. His theoretical transmission line carrying 30 000 volts, in the present stage of electrical practice, is hardly worthy of consideration.

Mr. Young says that "electrically operated pumps and drills are fully as efficient as those driven by compressed air, and more portable." This, in regard to drills, is an unfortunate statement, as there has never been an instance of a drill successfully worked by electricity; electricians themselves admit this. In regard to electrical pumps, the best that can be said for them is that they have been a great trial and disappointment to miners.

The auxiliary set of boilers was put in as a safeguard against a possible break in the water supply, as well as in the air machinery. The duplication of electrical machinery would cost more than the boilers and would be of no use in case of a water stoppage; and the boilers, moreover, are used as air reservoirs.

The air at the works before reheating carries about 150 H. P., which is about 50% of the theoretical power of the water. The inconvenience of reheating is largely imaginary. In the case under consideration, the firing, which is done by the motor-man, amounts to handling a cord of wood in twenty-four hours; and the heated air is used at a distance of from 50 ft. to 400 ft., transmitted in magnesia-covered pipes which are not hot externally and give no trouble. Mr. Foote.

In answer to Mr. Young's incidental request for the figures on a 10 000-H. P. 20-mile air transmission plant, the author refers him for information in that direction to Prof. Unwin and Gen. Haupt. As a suggestion, however, the probabilities are that the air would be compressed to about 2 000 lbs., and could be transmitted in two 6-in. pipes, costing possibly $8 000 per mile, losing, say, 30 per cent. By the use at the terminal station of what Mr. Rix calls a pneumatic transformer, this 30% would be regained. This pneumatic transformer consists of a triple expansion Corliss engine reheating between the cylinders, exhausting at 90 lbs., and running compound air compressors pumping air into the distributing system at 90 lbs. pressure.

The first part of Mr. Doble's discussion, referring to comparative costs, etc., is answered in the foregoing reply to Mr. Young, and in the accompanying table of costs:

Cost of Compressed Air Power Plant and Pipe Line.

Power House:		
Grading	$895 86	
Foundation and building	6 437 42	
Machinery in place	7 410 00	
Total for power house		$14 743 28
Aqueduct:		
Grading	$50 65	
Masonry	1 384 35	
Total for aqueduct		1 435 00
Pipe Line:		
Trench	$6 156 10	
Masonry	600 17	
Pipe and receiver in place	20 199 95	
Total for pipe line		26 956 22
Air pipe transmission line		463 10
Reheater at works		560 00
		$44 157 60

Mr. Foote. Rights of way, legal expenses, engineering and superintendence are not included in the foregoing table.

In reference to changing the nozzle of the wheel, the author would state that this takes less than five minutes, and the air reservoirs (boilers) are sufficient to keep the works going while it is being done.

Theoretical discussions and comparisons have their interest, but the hard facts of practical working are what the engineer values most. The North Star plant, though employing well-known principles, is somewhat novel in its combination and application of them. Being the first complete plant of the kind, from start to finish, it was fully expected that mistakes would be made, and changes required causing delays and stoppages. However, on the first of February of this year, the sinking pump, weighing 7 tons, was swung into the shaft and lowered to the water level by an engine working with reheated compressed air. A few days later another pump was installed in another shaft, some 800 ft. away; air was led to it through a pipe, and reheated in an old hot water heater. The combined capacity of the two pumps was 1 250 galls. per minute, and for a few days over four months these pumps averaged a constant stream lifted from the old mine of over 1 000 galls. per minute. At no time was there a stoppage of an hour's duration in the air machinery. Since then and up to the present writing*, additional pumps have been put in, an underground engine installed, and the mines worked generally in the usual manner, and still without delay or stoppage.

The enormous experience that has been attained in the use of steam and steam machinery is very largely applicable in the use of air; men understand it and are not afraid of it. To this fact, the author believes, is due in great measure the record that has been made by this new plant. Another advantage in the use of the air system, which is of great importance in mining, is the ventilation so easily and cheaply supplied by the exhaust air. In the case under discussion, one pump throws air into the face of a drift 300 ft. away, another into a stope 200 ft. away, where 20 men are working, a third into the bottom of an incline shaft which is being sunk; and in every place, men go back to their work within ten minutes after blasting, and this is done without extra expense, except for the piping, which would be required in any system of ventilation.

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* October 15th, 1896.